

1. Summary of Scientific Results

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ABSTRACT

The Apollo-Soyuz Test Project science and technology program conducted by the Apollo crew consisted of 28 separate experiments, including 5 conducted jointly with the Soyuz crew. Cosmic sources of extreme-ultraviolet and X-ray radiation were discovered. The interstellar medium in the vicinity of the solar system was investigated. The solar corona was photographed using spacecraft occultation of the solar disk. The radioactivation of potentially useful gamma-ray detectors by cosmic particle bombardment was measured, and the effects of cosmic particle impact upon living cells were investigated using three different techniques in three separate experiments. The concentrations of two atomic species and the aerosol component of the upper atmosphere were measured by resonance absorption spectroscopy and solar extinction photometry, respectively. The Earth surface structure was investigated using photographic and visual observations, and the subsurface structure was investigated by gravity-field measurements employing highly precise spacecraft-to-spacecraft tracking techniques. Zero-g effects on the embryogenesis of fish vestibular systems and on the rhythmicity of fungal growth patterns were investigated. Microbial growth and microbial transfer among crewmembers were measured. Mixtures of biological cells were separated into pure samples by use of two different electrophoresis techniques. Seven sets of solid materials were processed by high-temperature melting, and one set was processed by ambient-temperature diffusion.

INTRODUCTION

The Apollo crew participated in 28 scientific and technological experiments during the joint Apollo-Soyuz Test Project (ASTP) mission of July 1975. These experiments included five conducted jointly with the Soyuz crew and two provided by the Federal Republic of Germany. In addition to these unilateral Apollo and joint Apollo-Soyuz experiments, a number of unilateral Soyuz experiments were performed. This report summarizes only the 28 experiments falling into the first two categories. Together, the selected experiments formed a well-integrated program of complementary scientific objectives. In several cases, related experiments used different experimental techniques in pursuit of similar scientific objectives. The scientific results and operational experiences from these experiments are being used to determine the best techniques to pursue in future space missions. The experiments are listed by discipline and topic in table 1-I. The designations in parentheses denote the notation used for the jointly conducted experiments. The 28 experiments were selected from 161 proposals submitted from 9 countries (table 1-II).

The purpose of the ASTP Summary Science Report is to provide, in one document, a complete description of the experiment concepts, instrumentation, and operations; and to describe their results as provided by approximately 1 year of postmission analysis. The document is in two volumes; the second volume will pertain to the Earth Observations and Photography Experiment. This first volume pertains to all the other ASTP experiments.

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ASTP SUMMARY SCIENCE REPORT

TABLE 1-I.—ASTP Experiments

<i>Topic</i>	<i>Experiment no.</i>	<i>Experiment name</i>
<i>Space sciences</i>		
Astronomy	MA-048	Soft X-Ray Observations
	MA-083	Extreme Ultraviolet Survey
	MA-088	Interstellar Helium Glow
	MA-148	Artificial Solar Eclipse ^a (AS-4)
	MA-151	Crystal Activation
Earth studies	MA-059	Ultraviolet Absorption ^a (AS-5)
	MA-007	Stratospheric Aerosol Measurements
	MA-136	Earth Observations and Photography
	MA-089	Doppler Tracking
	MA-128	Geodynamics
<i>Life sciences</i>		
Particle radiation effects on living cells	MA-106	Light Flash Observations
	MA-107	Biostack III ^b
	MA-147	Zone-Forming Fungi ^a (AS-1)
Human immune system	AR-002	Microbial Exchange ^a (AS-2)
	MA-031	Cellular Immune Response
	MA-032	Polymorphonuclear Leukocyte Response
Vestibular system	MA-161	Killifish Hatching and Orientation
<i>Materials processing</i>		
Biological materials	MA-011	Electrophoresis Technology
	MA-014	Electrophoresis ^b
Solid materials	MA-010	Multipurpose Furnace
	MA-041	Surface-Tension-Induced Convection
	MA-044	Monotectic and Syntectic Alloys
	MA-060	Interface Marking in Crystals
	MA-070	Zero-g Processing of Magnets
	MA-085	Crystal Growth From the Vapor Phase
	MA-131	Halide Eutectic Growth
	MA-150	Multiple Materials Melting ^a (AS-3)
	MA-028	Crystal Growth

^aJoint U.S.-U.S.S.R. experiment.^bFederal Republic of Germany experiment.**ASTRONOMY**

The astronomy experiments are listed in table 1-I in order of the distance away from the Earth that the objects of study lie. The soft X-ray objects lie deep in our galaxy and even beyond our galaxy. The extreme-ultraviolet (EUV) objects lie within a few hundred light-years from the solar system, and the portion of the interstellar medium (ISM)

investigated in the Interstellar Helium Glow Experiment lies within a few astronomical units from the solar system. The corona photographed during the Artificial Solar Eclipse Experiment is within approximately 50 solar radii from the Sun. Finally, two crystal detectors that have potential application for future gamma-ray astronomy payloads were carried onboard the Apollo spacecraft to measure their susceptibility to

TABLE 1-II.—Experiment Proposals
Submitted to NASA

Origin	Number
United States	135
Federal Republic of Germany	8
France	7
India	4
U.S.S.R.	3
Ireland	1
Scotland	1
Sweden	1
Switzerland	1
TOTAL	161

radioactivation by local cosmic particle bombardment.

Concepts and Operations

The Soft X-Ray Observations Experiment was an attempt to obtain higher performance (viz, higher angular resolution) from a rocket-class instrument by taking advantage of the longer observing time available with an Earth-orbiting stabilized platform. The instrument (fig. 1-1), which was bolted into the scientific instrument bay of the Apollo service module, consisted of a gas proportional counter with an aluminum honeycomb collimator that provided a 4° circular field of view. Pointing of the instrument was accomplished by pointing of the spacecraft; there was no separate instrument pointing system. The three main objectives of the experiment were as follows.

1. To scan the celestial sphere to determine the structure of the known, soft X-ray background and hence possibly the source or sources of this background

2. To obtain the low-energy spectra of known X-ray sources for which higher energy spectra have previously been obtained so that distance estimates for these sources can be derived

3. To obtain high-time-resolution observations of discrete sources to discover X-ray pulsars

Soon after initiating operation, the instrument developed a high-voltage-breakdown characteristic that permitted operation only for periods of 2 minutes at a time. However, during those 2-minute periods, the instrument performed well, and new procedures were developed during the mission in near real time, which utilized the entire Apollo crew to properly phase spacecraft pointing and instrument switching. The result was a cumulation of approximately 1 hour of high-quality data that yielded successful achievements in all three objectives, especially the first and third.

The Extreme Ultraviolet Survey Experiment was an attempt to pioneer a new field of astronomy. Discrete sources of EUV radiation outside the solar system had never before been observed because EUV radiation (defined here as radiation with wavelengths between 10 and 100 nm) is highly susceptible to absorption by the ISM, which is mostly diffuse hydrogen gas. The previously supposed ISM density would not allow detectable amounts of EUV radiation to travel

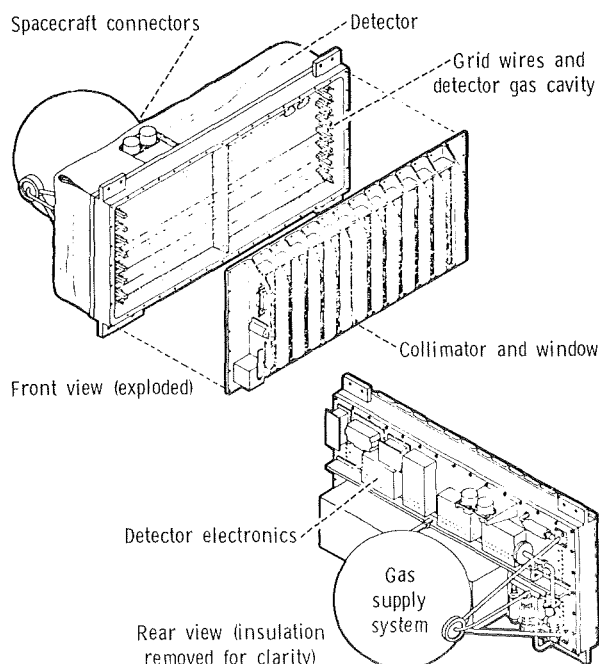


FIGURE 1-1.—Soft X-ray instrument.

more than a few tens of light-years, and few potential EUV sources exist within that distance of the solar system. Furthermore, the technology required for detecting faint EUV radiation was, to a large extent, undeveloped. In recent years, however, four favorable events occurred: The estimate of the ISM density decreased, observations in other wavelengths suggested that many strong EUV sources may exist within a few hundred light-years of the solar system, the requisite technology improved, and a suitable flight opportunity arrived. The instrument (fig. 1-2) consisted of grazing-incidence focusing optics, EUV-transmitting filters, and channel electron multiplier detectors. The EUV instrument was bolted into the service module instrument bay together with the soft X-ray instrument, and instrument pointing was achieved by spacecraft pointing. An in-flight pointing "raster scan" was performed to obtain precise definition of the instrument line-of-sight direction relative to the spacecraft axis. This exercise allowed the higher-resolution (2.5° field of view) detector to be used exclusively during the flight, which maximized the instrument sensitivity and contributed in a major way to the outstanding achievements of this experiment.

The Interstellar Helium Glow Experiment was an attempt to determine unambiguously the temperature and density of the ISM in the vicinity of the solar system. A by-product of the investiga-

tion was to be the determination of the velocity of the local ISM relative to the Sun. The technique was to detect EUV radiation originating from the Sun that is resonantly backscattered by the helium component of the ISM, specifically neutral helium (He I, 58.4 nm) and once-ionized helium (He II, 30.4 nm). Previous observations of the ultraviolet resonance line (Lyman α , 121.6 nm) of the ISM hydrogen component have not yielded definitive results because it is not possible to separate the solar-scattered contribution of that radiation from the unknown contribution transmitted through the ISM from galactic sources. However, as has been discussed, there should be little EUV radiation transmitted from great distances; therefore, the ambiguity is removed for the helium resonance radiation. Thus, the property of EUV radiation that poses problems for EUV stellar astronomy (high susceptibility to absorption by the ISM) is the very property that makes the Interstellar Helium Glow Experiment feasible. The instrument (fig. 1-3) utilized essentially the same technology as the EUV survey instrument, except that the grazing-incidence optics were nonfocusing, wide field-of-view collectors. The instrument was bolted into the service module instrument bay

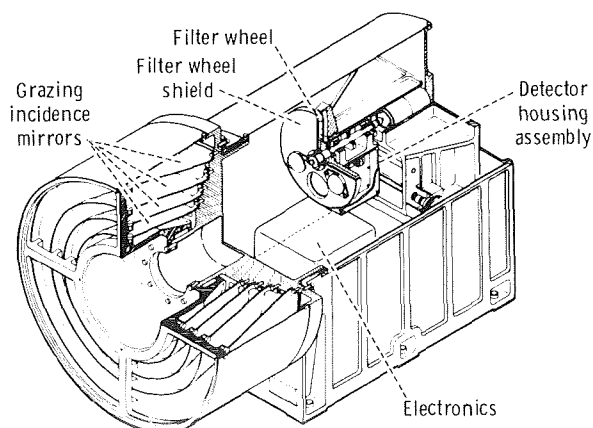


FIGURE 1-2.—Extreme-ultraviolet survey instrument.

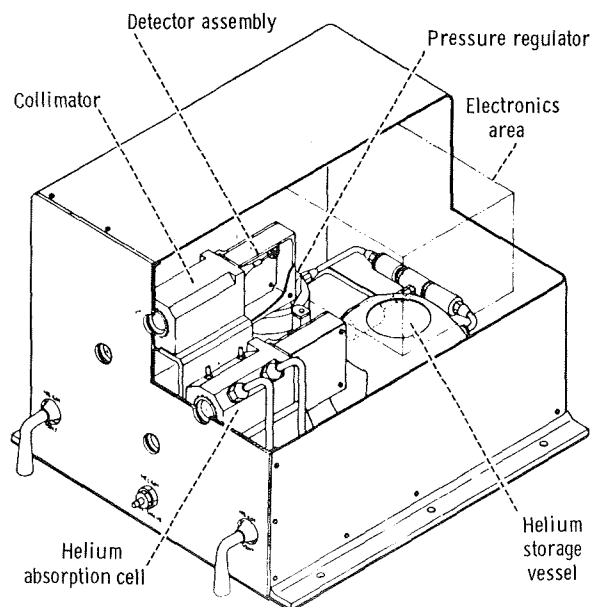


FIGURE 1-3.—Helium glow instrument.

with the soft X-ray and EUV instruments, and the entire sky was scanned by a series of spacecraft roll maneuvers. Although one of the detectors failed during the flight, the instrument functioned well, and 10 hours of data were obtained.

The Artificial Solar Eclipse Experiment was an attempt to demonstrate the feasibility of photographing the solar corona from one spacecraft by occulting the solar disk radiation with another spacecraft. The Apollo spacecraft backed away from the Soyuz spacecraft in the solar direction (fig. 1-4) until, at a separation of approximately 200 m, the Apollo subtended an angle of approximately 2 solar diameters, as seen from Soyuz. Soyuz photography was performed in the solar direction through a vignetting light baffle designed to block the bright sunlight reflected from the Earth beyond the terminator. All operations were performed successfully.

The Crystal Activation Experiment was an attempt to learn more about the propensity of certain types of crystals to be radioactivated by particle bombardment in the Earth-orbital environment. The crystals (germanium and thallium-

activated sodium iodide) are potentially important for use as detectors in future gamma-ray astronomy payloads. The problem is that cosmic-ray particles such as high-energy protons (and secondary neutrons produced in the spacecraft structure by these protons) can induce X-ray and gamma-ray activity by way of spallation interactions with the detector material. This detector background cannot be distinguished from the signal produced by incident gamma rays; hence, it is difficult to account for the background contribution to the total signal when attempting to measure the intensity of gamma rays coming from astronomical sources. Consequently, the background properties of the detectors must be investigated separately, as in this experiment. The experiment consisted of carrying a sample of each of the crystals into orbit and then measuring the induced radioactivity after the mission. To detect the short-half-life species, the measurements began on the recovery ship approximately 1.5 hours after atmospheric reentry of the command module. Those and subsequent laboratory measurements were successful.

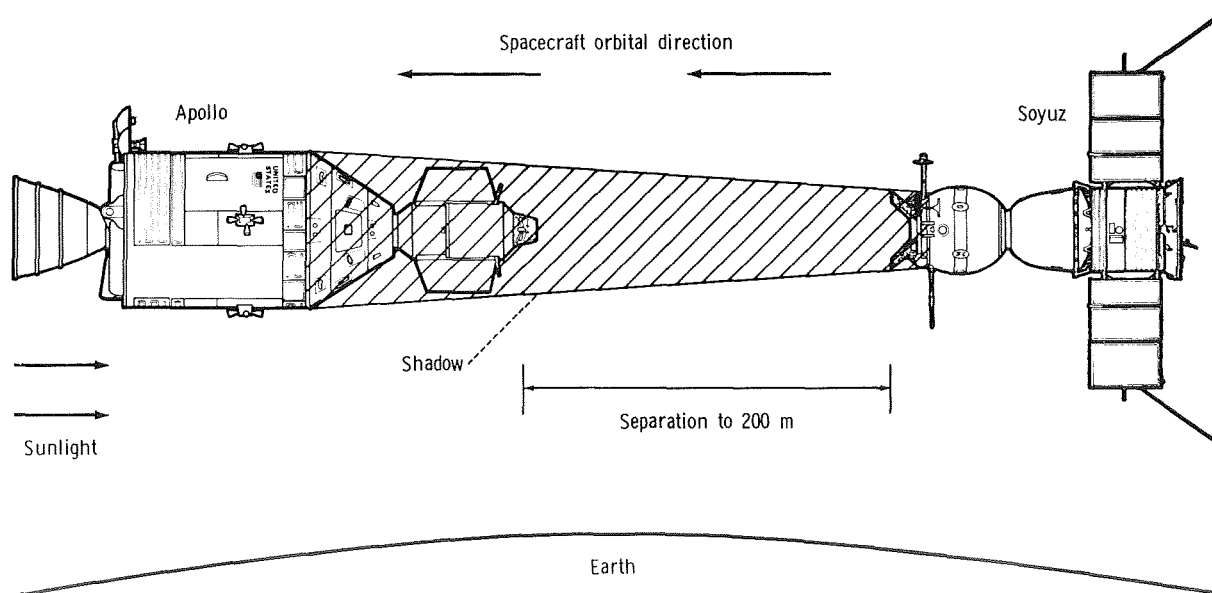


FIGURE 1-4.—Spacecraft orientation for artificial solar eclipse.

Results

The Soft X-ray Observations Experiment resulted in several important discoveries. For example, the previously known binary X-ray source in the Small Magellanic Cloud (a companion galaxy of our galaxy), SMC X-1, was discovered to be an X-ray pulsar as well, thus identifying the compact component of the binary to be a rotating neutron star. This is the first pulsar discovered outside our galaxy, and it has the shortest pulse period (0.7157 second) of any known X-ray binary pulsar. Two important observations of extended structure in the soft X-ray background were obtained. The first is associated with a known (optically) supernova remnant in the constellation Centaurus. The second is a previously known X-ray source in the constellation Cygnus, designated Cyg X-6. However, the ASTP observations in conjunction with a rocket experiment by the same investigators, have shown for the first time that Cyg X-6 is an extended X-ray source and is not associated with any optical or radio object.

The Extreme Ultraviolet Survey Experiment achieved the first detection of discrete sources of EUV radiation outside the solar system. To date, four such sources have been positively identified in the data. They are stars that were previously known optically to be the white dwarfs HZ 43 and Feige 24, the dwarf nova SS Cygni, and the M-dwarf flare star Proxima Centauri. The two most intense sources are the white dwarfs, and this experiment determined that they are much hotter than was previously believed. In fact, they are now the hottest, most luminous white dwarfs known; preliminary analysis indicates the effective temperature of HZ 43 may be 110 000 K, at which temperature it would be the first known white dwarf whose total luminosity exceeds that of the Sun. The EUV data were also useful in providing more reliable estimates of the ISM mean densities in the directions of the white dwarfs: 0.01 to 0.02 hydrogen atoms cm^{-3} . The dramatic new physical interpretation for the EUV objects establishes the importance of observing such objects at EUV wavelengths when their peak energy emission occurs at those wavelengths. Thus, this

experiment has provided strong indication that the new field of EUV stellar astronomy may become important.

The Interstellar Helium Glow Experiment analysis is still underway. No definite conclusions have been obtained at this writing; no current theoretical models fit the data in their present state of analysis.

Data from the Artificial Solar Eclipse Experiment were analyzed exclusively by the U.S.S.R. investigators, and their results are published in this document. They report that the corona is detectable on 19 of the 55 exposures suitable for analysis, and they have obtained a coronal intensity distribution along the ecliptic westward from the Sun which extends to nearly 50 solar radii.

Results of the Crystal Activation Experiment indicated that, because of the geomagnetic shielding of the low ASTP orbit, the induced activation was a factor of 3 less than that incurred on a similar experiment flown on the Apollo 17 lunar mission. The contribution to the activation by secondary neutrons demonstrates that such detectors used in gamma-ray astronomy experiments should be placed far from heavy material.

EARTH STUDIES

The Earth studies experiments are listed in table 1-I in order of the distance above the Earth's surface that the subjects of study are located. The Ultraviolet Absorption Experiment was an investigation of the atomic composition of the tenuous upper atmosphere at the spacecraft altitude, and the Stratospheric Aerosol Measurements Experiment measured the aerosols in the tropopause at an altitude of approximately 20 km. The Earth Observations and Photography Experiment studied a multitude of Earth surface features on land and in the oceans, and the Earth subsurface structure was investigated by means of two variations of gravity-field measurements with two spacecraft-to-spacecraft tracking experiments, the Doppler Tracking Experiment and the Geodynamics Experiment.

Concepts and Operations

The Ultraviolet Absorption Experiment was an attempt to apply a new technique, resonance absorption spectroscopy, to the investigation of the upper atmosphere. This technique had never before been employed in a space mission experiment, and it appeared feasible to measure the concentrations of neutral atomic oxygen (O) and neutral atomic nitrogen (N) at the relatively low ASTP orbital altitude of 220 km. The former measurement would serve as a comparison with previous results from mass spectrometry experiments, and the latter measurement would constitute the first reliable measurement of N at such altitudes. Thus, this experiment could provide a first assessment of a technique that might be developed as a powerful method for measuring and monitoring the constituents of the upper atmosphere. The concept of the experiment was to produce collimated beams of resonance radiation for O and N on the Apollo spacecraft and illuminate an array of corner reflectors mounted on the Soyuz spacecraft at a known distance from Apollo. The portion of the beam striking the retroreflectors was returned to a collecting mirror on the docking module and was focused on the entrance slit of a spectrophotometer. To prevent Doppler effects (due to spacecraft orbital velocity) from shifting the lamp frequency away from the atmospheric absorption frequency, it was necessary to maneuver the Apollo spacecraft such that the light beams traveled between the two spacecraft perpendicularly to their orbital velocity vectors. Primarily because of this constraint, the spacecraft maneuvers required for the three data takes (at approximate spacecraft separations of 150, 500, and 1000 m) became the most intricately planned maneuvers ever performed by an Apollo spacecraft during a scientific experiment. Figure 1-5 shows the planned maneuver schematic for the 500-m data take. A reflected signal (resonance absorption data) was obtained for this run but not for the 150-m data take and only sporadically for the 1000-m data take. An anomaly occurred during the 500-m data take that has been interpreted as a degradation of the corner reflectors. Reso-

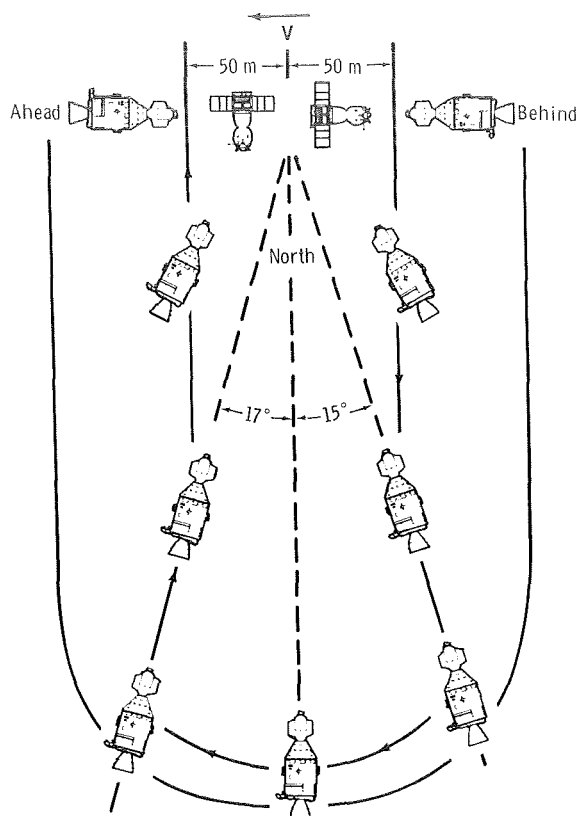


FIGURE 1-5.—Spacecraft maneuver for Ultraviolet Absorption Experiment.

nance fluorescence (resonance scattering) data were obtained during the 150-m data take.

The Stratospheric Aerosol Measurements Experiment was an attempt to perform the first remote sensing of the atmospheric aerosol layers from an orbiting spacecraft, using solar extinction photometry. The concept was to monitor the extinction of direct sunlight at orbital sunrise and sunset, as the Sun-spacecraft line of sight traversed upward and downward through the lower 150 km of atmosphere (fig. 1-6). For this purpose, a photometer sensitive to $1\text{-}\mu\text{m}$ radiation (the wavelength range most sensitive to aerosol extinction) was mounted in a command module window and data were collected during two sunsets (Northern Hemisphere) and two sunrises (Southern Hemisphere). High-quality data were obtained.

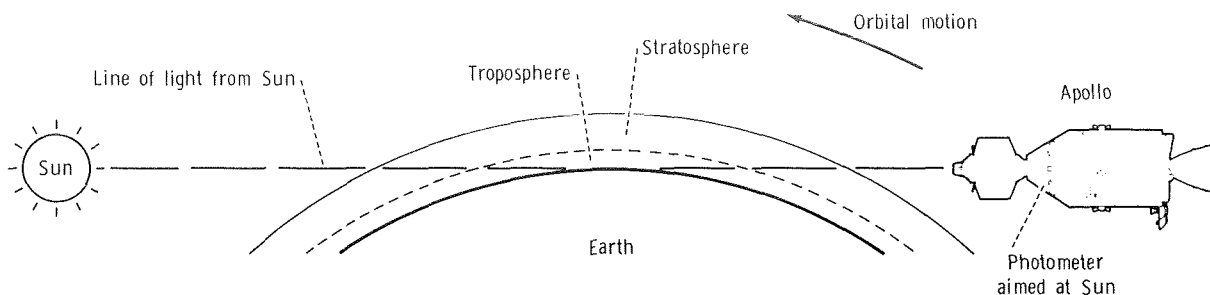


FIGURE 1-6.—Sunrise orientation for stratospheric aerosol measurements.

The Earth Observations and Photography Experiment was an attempt to use the recognition and interpretive capabilities of human observers to refine the selection of Earth surface features for photography and to provide *in situ* contributions to analysis of these features. The phenomena to be observed were selected from the categories of geology, deserts, oceanography, hydrology, and meteorology. For the ASTP experiment, a Principal Investigator assembled a team of scientific investigators representing topics of special interest in the previously mentioned fields. A comprehensive crew training program involving classroom studies and aircraft flyover exercises was conducted, and an extensive flight-planning effort was made to ensure the acquisitions of as much data as real-time cloud cover would allow. Many useful observations and photographs were obtained. Postmission data assessment was used to define a scientific analysis program that is underway at the time of this writing.

The Doppler Tracking Experiment was one of two ASTP experiments that represented attempts to test the feasibility of performing refined measurements of the Earth's gravity-field structure with horizontal scale sizes of approximately 250 to 1000 km. Such measurements would be useful in describing the subsurface structure of the Earth to depths of several hundred kilometers, and it is anticipated that such information would have great importance for understanding tectonic plate processes. Surface gravimetry is useful only for gravity structure determinations on a scale of less than approximately 100 km, and single-satellite orbit perturbation measurements are useful only for scale sizes greater than 2000 km. In principle, however, two spacecraft in orbit can

recover the gravity-field structure of the desired scale size by performing very high accuracy Doppler measurements between the vehicles while one of them is being accelerated by the gravity-field anomaly. Roughly, the smallest anomaly scale size recoverable is about equal to the altitude of the lower spacecraft, and the largest scale size is comparable to the separation of the spacecraft. The spacecraft-to-spacecraft tracking technique used in the Doppler Tracking Experiment was the low-low technique, in which the two spacecraft traveled in the same orbit at some suitable separation (fig. 1-7). The two spacecraft were the Apollo command and service module (CSM) and the docking module, which was jettisoned from the CSM in a spin-stabilized mode (end over end) for the purpose of this experiment. A transmitter in the docking module provided phase-coherent

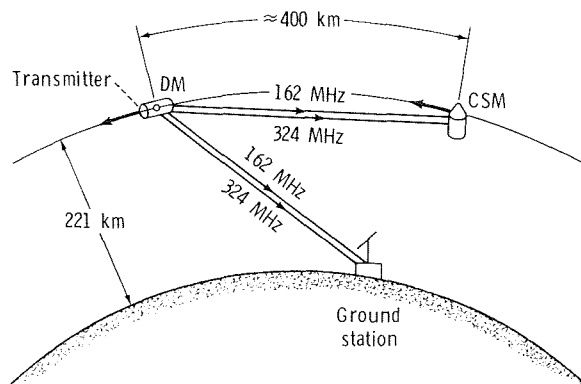


FIGURE 1-7.—Doppler tracking low-low spacecraft orientation.

dual-frequency transmission to the CSM to account for ionospheric effects in the Doppler measurement. This feature introduced the possibility of studying the horizontal scale of electron concentrations in the ionosphere and of detecting traveling ionospheric disturbances and boundaries of ionospheric turbulence. Consequently, ionospheric studies became a secondary objective of the experiment. After the docking module was jettisoned, the CSM moved to an initial separation distance of 310 km and drifted to a separation distance of 430 km by the end of the data take (nine revolutions later, approximately 14 hours).

The Geodynamics Experiment was the other ASTP experiment designed to detect and recover gravity-field fine structure, and it used the high-low spacecraft-to-spacecraft tracking technique. The low spacecraft was the Apollo vehicle, and the high spacecraft was the geosynchronous Applications Technology Satellite (ATS) 6, which was located over the east coast of Africa during the experiment (fig. 1-8). The Geodynamics Experiment data link in figure 1-8 was from the ATS ranging station in Madrid to ATS-6, to Apollo,

back to ATS-6, and to Madrid. The Apollo Spaceflight Tracking and Data Network (STDN) link was used for spacecraft orbit determination. The experiment involved no dedicated spacecraft hardware; the Apollo/ATS-6 communications link was developed for other reasons. Data were acquired on 108 passes under the ATS-6 spacecraft.

Results

The Ultraviolet Absorption Experiment successfully measured the concentrations of O and N at the ASTP altitude. The values were obtained by combining the resonance fluorescence data of the 150-m data take with combined fluorescence and absorption data of the 500-m data take. Preliminary values are $[O] = 1.15 \times 10^9 \text{ cm}^{-3}$ and $[N] = 8.6 \times 10^6 \text{ cm}^{-3}$. Continuing analysis is expected to refine these values, but they are already in good agreement with the oxygen measurements of the Atmospheric Explorer Satellite extrapolated to the time and location of the ASTP measurements.

The Stratospheric Aerosol Measurements Experiment yielded high-quality photometry and photography results. The aerosol layer peaked at an altitude of approximately 20 km in the Northern Hemisphere and somewhat lower in the Southern Hemisphere; the peak concentration was approximately 50 percent higher in the Northern Hemisphere. These results, combined with balloon-sampling measurements made in Australia before and after the ASTP mission, are consistent with seasonal, meridional transport of aerosols after the eruption of Volcan de Fuego in Guatemala in October 1974. The results are very encouraging for developing the solar extinction technique for long-term spaceborne monitoring of the Earth's atmosphere.

The Earth Observations and Photography Experiment data have been assessed, and an analysis program has been defined and is underway. Because the analysis program was delayed until postmission data assessment was completed, the scientific results will be reported in volume II of the ASTP Summary Science Report.

The Doppler Tracking Experiment was not

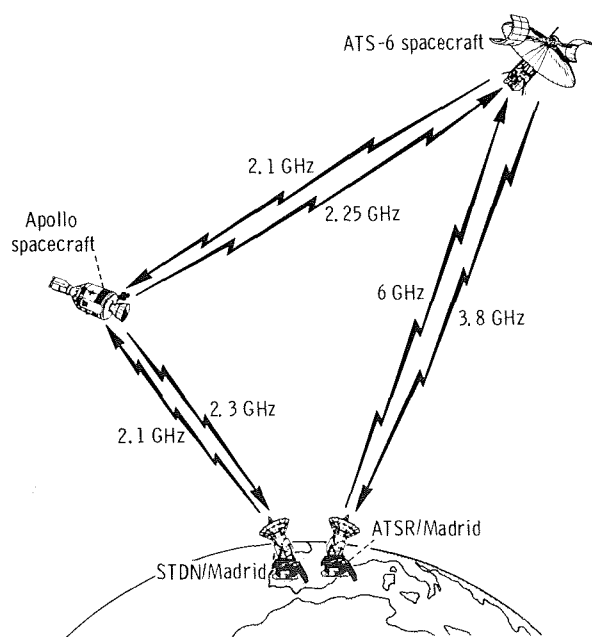


FIGURE 1-8.—Geodynamics high-low spacecraft orientation.

able to achieve its prime objective of measuring gravity-field anomalies. The data were degraded by a single-frequency noise level much higher than anticipated and too high to allow extraction of gravity-field signatures. The source of the noise is not known. The ionospheric investigation was highly successful. Analysis is continuing, but preliminary results are as follows.

1. Changes in the columnar electron content between the two spacecraft were accurately measured and yielded gradients as high as 10^6 electrons $\text{m}^{-3} \text{m}^{-1}$ on both the dayside (typical density, 5×10^{11} electrons/ m^3) and nightside (typical density, 3×10^9 electrons/ m^3) ionosphere.

2. Traveling ionospheric disturbances were detected; the most noticeable one occurred off the coast of California. This disturbance was a nine-cycle wave with peak-to-peak electron density perturbation of 35 percent, with wavelength of 690 km (as would be seen from the ground), and with spatial extent of 7200 km along the Apollo orbital track. The ionospheric results from the Doppler Tracking Experiment are particularly noteworthy because they are the first such measurements of the ionosphere in the region of 200 km altitude.

The Geodynamics Experiment resulted in successful detection and recovery of gravity-field signatures with resolution within 0.010 cm/sec^2 (10 mgal). Areas in which such anomalies were recovered are the Indian Ocean Depression, the Himalayan Anomalous Region, an area in west central Africa near the Banqui magnetic anomaly, and the Zagros thrust zone, which is at the juncture of the African and Eurasian tectonic plates. The high-quality gravity measurements of the Geodynamics Experiment were an extremely encouraging demonstration of the validity of the high-low spacecraft-to-spacecraft tracking technique. This technique may be developed to provide global coverage for gravity-field measurements with future space projects. An additional benefit from the Geodynamics Experiment was the use of the data for tropospheric studies. Analysis of the atmospheric refraction of the Apollo/ATS link near the horizon yielded refractivity, pressure, and temperature profiles that closely matched radiosonde determinations. This result has potential application for space monitor-

ing of meteorological properties of the troposphere.

PARTICLE RADIATION EFFECTS ON LIVING CELLS

With the advent of space flight, interest arose as to the effects upon humans and other living organisms of exposure to cosmic particle radiation. While the effects of protons are now fairly well understood, recent interest has developed in understanding the implications of the highly charged and energetic (HZE) component of cosmic rays for long-duration space travel. Such particles can deposit energy in tissue at a linear rate exceeding $1 \text{ GeV cm}^2 \text{ g}^{-1}$, and such energy deposition is capable of killing a cell if the particle passes sufficiently near the cell nucleus. The implications are particularly important for nonregenerative cells such as those in the central nervous system. Three ASTP experiments were designed to investigate the effects of HZE impact on living cells. The Light Flash Observations Experiment yielded measurements of visual effects produced by impact with the astronauts' eyes, the Biostack III Experiment yielded measurements of mutations eventually produced in animals and plants that were flown in the dormant stage (egg, seed), and the Zone-Forming Fungi Experiment was an attempt to observe the real-time mutations that might occur in a ring of fungal cells as they grew during the flight.

Concepts and Operations

The light flash experiment was an attempt to record the visual sensations caused by impact of HZE particles on the dark-adapted retinæ of two astronauts, and to correlate their observations of the intensities and shapes of the resulting flashes with measurements by particle detectors placed close to the astronauts' eyes. The objective was to determine quantitatively the frequency, character, latitudinal dependence, and identity of cosmic particles that cause the flash phenomena. The ultimate objective is to assess the radiation hazards

for long-duration, Earth-orbiting and interplanetary missions. The two detectors used were a silver chloride crystal device that measured particle identity and energy transfer, and a silicon solid-state device that measured particle spectra (energies) and directions and also provided better time resolution than the silver chloride crystals. The orientation of the retinæ with respect to the Earth's magnetic field (fig. 1-9) was important for interpreting the flashes. Data were obtained on two orbits, one of them using only the solid-state detector.

The Biostack III Experiment was an attempt to confirm and extend the studies of HZE particle impact on biological systems begun with the Biostack I and II Experiments during the Apollo 16 and 17 missions. A feature of the ASTP mission was that the geomagnetic shielding yielded a radiation dose an order of magnitude lower than on the lunar missions. The experiment consisted of two cylindrical containers with layers of dormant biological objects interleaved with sheets of particle detectors. The interleaving enabled accurate determination of the location of the hits on the biological objects, which consisted of plant seeds and eggs of lower animals such as brine shrimp.

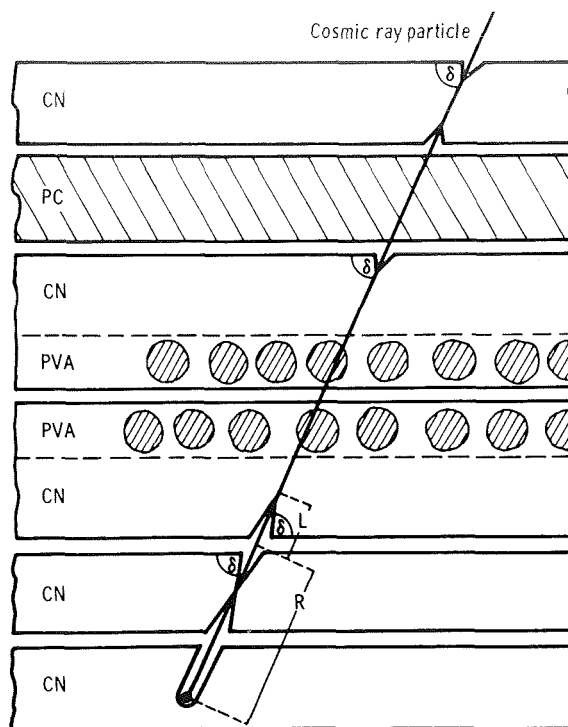


FIGURE 1-10.—Biostack III typical sample/detector layers.

Figure 1-10 shows a representative section of one of the cylinders. The dip angle δ helps locate the impacted biological object, the cone length L determines energy loss, and the residual range R determines particle charge. The cylinders were stored in the command module in a location of minimum shielding to ambient cosmic radiation.

The Zone-Forming Fungi Experiment had two objectives. One objective was to study radiation effects, especially HZE-impact effects, upon the growth rates and development of growing cultures of *Streptomyces* (*Actinomyces* in the U.S.S.R.) *levoris* Kras carried onboard the two spacecraft. The other objective was to ascertain the possible effect of space-flight factors on the rhythmicity of the growth patterns exhibited in the cultures. The cultures were grown in Petri dishes with particle detectors placed above and below the dishes for determination of particle impact characteristics. Two such assemblies were packaged together in a device (fig. 1-11), and two such devices were

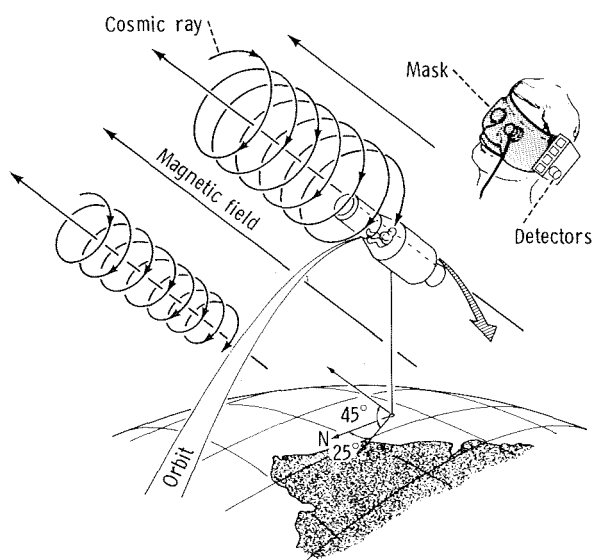


FIGURE 1-9.—Orientation for light flash experiment.

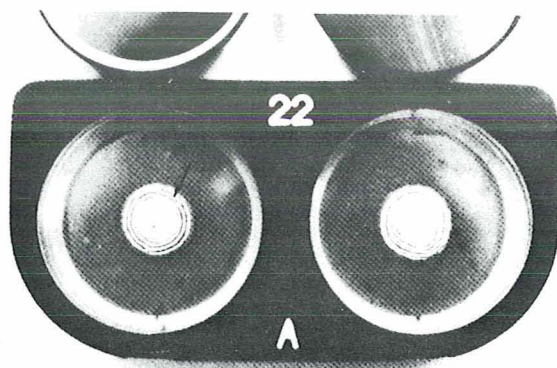


FIGURE 1-11.—Zone-forming fungi culture device.

launched in each spacecraft. During the docked portion of the flight, one device from each spacecraft was exchanged.

Results

The light flash experiment data for the silver chloride crystals did not correlate well with either the astronaut event-rate observations or the abundances calculated for the ASTP altitude. This discrepancy was probably due to inadequate time resolution for the crystals (viz, the decay time of unfixed heavy-ion tracks was too long). The events observed in the region of the South Atlantic Anomaly, when compared to similar observations performed during the Skylab 4 mission (at an altitude of 440 km), suggest a physical interpretation for the mechanism of light flash production. This mechanism is inelastic collisions of protons with nuclei of carbon, nitrogen, or oxygen in the retina. The arguments leading to this interpretation include the relative abundances of protons with energy loss $\geq 15 \text{ keV } \mu\text{m}^{-1}$ at the two altitudes, the relative shielding of the spacecraft (Skylab shielding was much less than that of the command module), and the orientation of the retina with respect to the magnetic field in the South Atlantic Anomaly.

The Biostack III Experiment analysis is partially completed. The biological objects that underwent impact have been identified. Objects adjacent to them are being used as controls. Growth and development studies and genetic studies are

still in progress. Preliminary results are as follows.

1. Growth of *Bacillus subtilis* spores was significantly reduced for impacts of particles that passed within $4 \mu\text{m}$ of the spore centers.

2. Seeds of *Zea mays* showed significant retardation in growth and development, and two impacted seeds failed to germinate.

3. No effects have yet been detected on the germination, growth, and development of the impacted seeds of *Arabidopsis thaliana*.

4. Most of the impacted animal eggs showed serious damage during development. For example, the *Artemia salina* eggs displayed a significantly reduced hatching rate, and developmental anomalies at the extremities and at the abdomen were evident.

In comparison of the dosimetry results of Biostack III with those of Biostack I and II, it was noted that, despite the much lower radiation dose for the ASTP mission, the Biostack III frequency of nuclear disintegration stars was nearly twice that of Biostack II. Little is known about their potential biological effects, but increased attention is being given to nuclear stars in the Biostack III analysis, especially since this radiation component reaches maximum intensity at altitudes of approximately 20 km, which is the region of the atmosphere where supersonic transports fly.

The Zone-Forming Fungi Experiment results showed that definite differences occurred among the various cultures in their zone growth rates and morphologies, but the differences occurred non-uniformly. No specific property of space flight (for example, HZE radiation or weightlessness) can be correlated with any of the observed differences. Investigations are continuing to determine whether the resulting abnormal spore morphology will appear in subculture.

HUMAN IMMUNE SYSTEM

The investigation of the effect of space-flight factors on the infectious disease process has been a continuing one in both the United States and the U.S.S.R. since the advent of the space program. The ASTP mission provided a unique opportunity to study the process because of the relatively large number of subjects (five crewmen and two

spacecraft) that originated from widely separated environments and that were suddenly brought together under space-flight conditions. The Apollo-Soyuz investigation of the immune system comprised three experiments. The Microbial Exchange Experiment emphasized measurements of several microbial species but also included measurements of species-specific antibodies. The Cellular Immune Response Experiment and Polymorphonuclear Leukocyte Response Experiment investigated cell function.

Concepts and Operations

The Microbial Exchange Experiment was an attempt to monitor alterations in three factors: the composition of microbial populations inhabiting the Apollo and Soyuz crewmembers and spacecraft, the ability of each crewmember to resist infection, and the ability of certain microorganisms to cause infection. The purpose was to address the overall problem of space-flight effects on the balance between the immune system and infectious microorganisms. Because the two crews came from widely separated geographical and ecological areas, it was possible to identify specific marker microbes for study of cross-contamination patterns. The autoflora and immunocompetence levels of each crewmember were established through repeated sampling and analyses before flight so that flight changes could be measured and intercrew transfer of marker organisms could be identified. Likewise, certain immunological parameters of the blood and saliva of each crewmember were studied to detect changes in the ability of the person to resist infection. This was the first space experiment to monitor species-specific antibodies. During flight, microbial samples were obtained by specially designed swabs (fig. 1-12) from 15 areas in each spacecraft and from 6 locations on each crewmember. The devices were launched and recovered in the Soyuz spacecraft, and initial laboratory studies were performed in Moscow by U.S. and U.S.S.R. investigators.

The Cellular Immune Response Experiment and Polymorphonuclear Leukocyte Response Experiment were laboratory investigations of im-

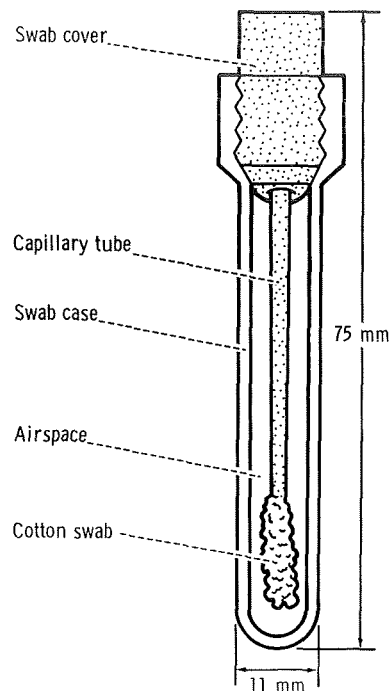


FIGURE 1-12.—Microbial exchange collection device.

une system cell function as affected by space-flight factors. These studies involved blood sample analysis before and after the mission; no in-flight data were acquired. The investigations pertained only to the Apollo crewmembers. In the former experiment, the parameters studied were white blood cell concentrations, lymphocyte numbers, B- and T-lymphocyte distributions in peripheral blood, and lymphocyte responsiveness. In the latter experiment, the studies included total leukocyte count, differential count, measurement of leukocyte adhesion, evaluation of leukocyte migration and chemotaxis, and assessment of phagocytic ability.

Results

The Microbial Exchange Experiment results were consistent with those of studies on previous missions and added results unique to ASTP. A variety of potential pathogens were recovered from each of the prime and backup crewmembers before and after the flight, but no disease events

occurred. The yeast *Candida albicans* and the bacteria *Staphylococcus aureus* were transferred from one Apollo crewmember to another, but no microbial transfer occurred between crews. No other medically significant changes in the microbial population occurred. The total load of aerobic bacteria inhabiting the skin and upper respiratory tract was essentially the same for all 10 crewmembers and was not significantly changed during flight. Likewise, no significant change in the presence of species-specific antibodies could be attributed to the mission.

The Cellular Immune Response Experiment analysis showed significant depression of the lymphocyte responsiveness from premission levels, but the lymphocyte population remained essentially unchanged. The possibility that the immunosuppression was caused by inhalation of toxic gases rather than usual space-flight factors cannot be assessed; no data are available on the effects of toxic gases on lymphocytic responses. Similar response depression was not observed on the various Apollo lunar missions, but it was observed on the much longer Skylab 3 and 4 missions.

The Polymorphonuclear Leukocyte Response Experiment analysis detected no substantial change in the leukocyte functions from premission tests. It is noted, however, that the time scale for turnover of the leukocytes, from insertion into the bloodstream by the bone marrow to deposit in the tissues, is only a few hours. Thus, the postmission leukocytes tested were not the ones present during weightlessness, so it is not possible to describe the changes in leukocyte function as a function of time of exposure to space-flight conditions. Thus, this study cannot draw conclusions on the possible effects of extended missions on leukocyte function.

VESTIBULAR SYSTEM

Concepts and Operations

The Killifish Hatching and Orientation Experiment was the second in a series to determine the effects of space flight on certain portions of the life cycle of certain organisms. The emphasis was on the function and development of the vestibular

system and on calcium metabolism as it related to otolith development. A similar experiment in demonstration form was conducted during the Skylab 3 mission. The Skylab experiment consisted of a plastic bag of synthetic seawater containing 2 juvenile killifish (*Fundulus heteroclitus*) and another bag containing 50 fertilized eggs. The juveniles exhibited looping swimming motion for several days, until they gradually adapted to visual cues for orientation. The orbit-hatched fry, however, exhibited no initial disorientation. They appeared to depend on visual cues for orientation in orbit, and those alive after recovery appeared to depend only on visual cues for orientation on the recovery ship, with no vestibular input. The animals died soon after recovery and were not preserved sufficiently to prevent deterioration. Typical otoliths were not visible in microscopic sections of these fish. The Apollo-Soyuz experiment was designed to extend the Skylab experiment, with emphasis on vestibular disturbance and embryonic development. Since otolith development is largely a matter of calcium metabolism, study of the otolith development was important not only for understanding the effects of space flight on the vestibular system, but possibly for using the otolith as a model for space research on calcium metabolism in general. The experiment consisted of two sets of five seawater-filled plastic bags. One set contained immature fry (21 days old at launch) that had been reared from hatching in tanks presenting various visual environments. The other set contained numbers of fertilized eggs of different ages since fertilization. Figure 1-13 is a photograph of the two sets of bags. The data consisted of filming the swimming behavior of the juveniles and the orbit-hatchlings at various stages of the mission. Postflight analysis included swimming-behavior testing, light and electron microscopy of the vestibular system, and continued zero-g aircraft testing.

Results

The Killifish Hatching and Orientation Experiment analysis revealed that both the juveniles and the hatchlings exhibited normal vestibular function after flight. The juveniles' postflight swimming patterns suggested abnormal swim bladders.

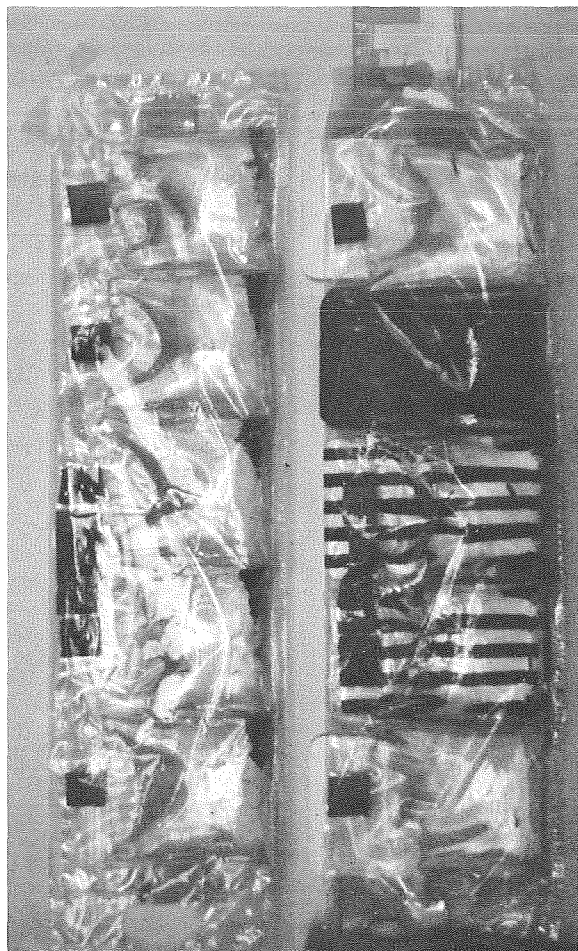


FIGURE 1-13.—Killifish egg and fish containers.

Subsequent testing of maturing fish implied subtle changes in geotactic response and enhanced sensitization to environmental influences as compared with controls. Microscopy has revealed no significant effects on the development of the central nervous system, the peripheral vestibular apparatus, the eye, or the cardiovascular system.

BIOLOGICAL MATERIALS PROCESSING

For various types of biological research, it is necessary to acquire pure samples of single-type live cells from a mixture of different types of live cells. The separation process is often not amenable to centrifuge or filter techniques because the

different types of cells are not sufficiently dissimilar in size, shape, or mass, and the cells may be too fragile to survive in a viable form.

Electrophoresis is a separation method based on the fact that live cells have a surface charge, the quantity of which is related to the cells' biological function. Thus, if a mixture of different types of cells is placed in an electrolytic buffer solution (the composition of which is compatible with the biological vitality of the cells), and if an electric field is applied, the different types of cells should separate into individual zones according to their individual electrophoretic mobilities. However, in ground-based laboratories, the performance of the electrophoresis process is limited by effects that are mostly associated with a one-g environment. For example, the density difference between cell zones and the buffer solution often causes sedimentation, and Joule heating of the electrophoretic column by the electric field often causes destabilizing convection currents. In principle, these performance limitations may be eliminated in a zero-g or micro-g environment. On the Apollo-Soyuz mission, two experiments successfully demonstrated, for the first time in a space environment, two types of electrophoresis. They were the Electrophoresis Technology Experiment and the Electrophoresis Experiment.

Concepts and Operations

The Electrophoresis Technology Experiment was an attempt to demonstrate the static column, or zonal, method by electrophoresing several sets of mixtures of cells. The method uses a static column of buffer solution (fig. 1-14) with the electric field aligned along the column. A sample of cell mixture is introduced at one end, and the individual cell zones travel down the column at different speeds. Five different mixtures of cells were to be processed: a mixture of rabbit, human, and horse fixed red blood cells; human peripheral blood lymphocytes; human fetal kidney cells; fixed rabbit and human red blood cells; and fresh rabbit and human red blood cells. The last two mixtures were processed by means of

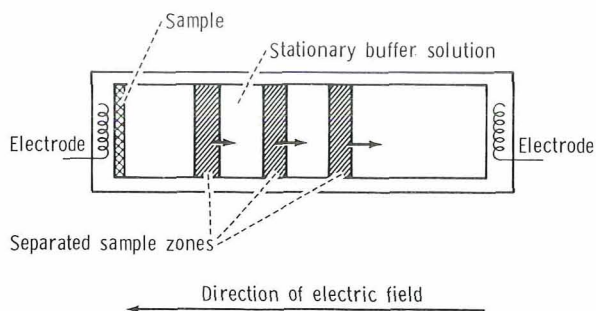


FIGURE 1-14.—Electrophoresis technology static column concept.

isotachopheresis, which is a zone-boundary-sharpening type of zonal electrophoresis. The interest in processing kidney cells was to assess the feasibility of isolating urokinase-producing cells. Urokinase is an enzyme that has the ability to dissolve blood clots, and there is much interest in this enzyme for eventual medical application. The supply of urokinase is far too low to meet the demands, and although it is obtainable from cultures of kidney cells, only 5 percent of the cells in the kidney cortex produce it. If urokinase-producing cells can be isolated from the rest, for example by space processing, the potential exists for increased rates of production. To assess this possibility, a pharmaceutical company participated in the kidney cell processing portion of this experiment. The various mixtures (eight in all, because the first three were duplicated) were launched in a cryogenic freezer to maintain cell viability. After the mixtures were processed, the columns were frozen with the cell zones in place, and they were stored and returned in the freezer for laboratory analysis. Thus, this experiment addressed the three technological requirements for eventual application of electrophoresis on space missions: (1) preservation of cell viability before processing, (2) processing, and (3) preservation of viability after processing.

The Electrophoresis Experiment was an attempt to demonstrate improved performance of the free-flow method in a micro-g environment over that attainable on the ground. In this method, the buffer solution flows continuously (fig. 1-15), and the cell mixture is continuously inserted into

the flow. The electric field is aligned perpendicularly to the flow so that the cells separate from each other laterally into streams. Four mixtures were processed in this experiment: rat bone marrow cells, fixed rabbit and human red blood cells, rat spleen cells, and rat lymph node cells with human red blood cells as markers. Except for the mixture of fixed cells, the mixtures were freshly prepared before they were launched in the Apollo command module. The rat lymph cells were frozen (stored in the cryogenic freezer of the Electrophoresis Technology Experiment) and the others were cooled until processing began approximately 1 day after launch. The separated streams were detected photo-optically and the data were stored on magnetic tape; no attempt was made to preserve the cells after processing.

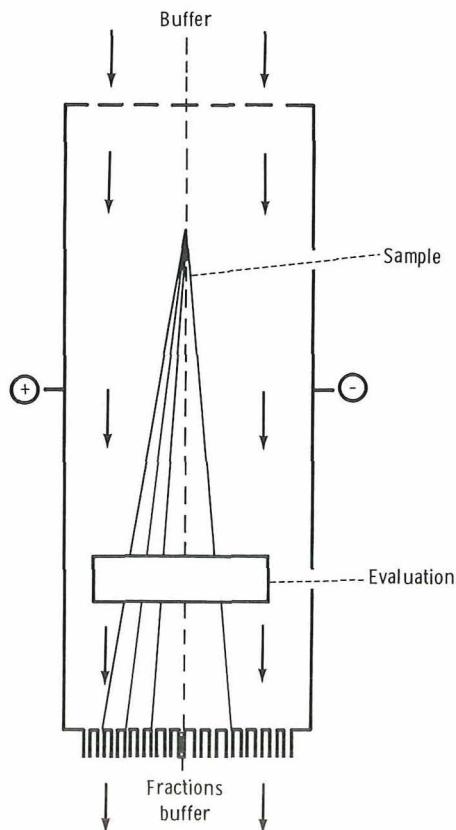


FIGURE 1-15.—Electrophoresis continuous flow concept.

Results

The Electrophoresis Technology Experiment, by separating the fixed red blood cell species from their mixture, provided the first successful demonstration of zonal electrophoresis in a space environment. The lymphocytes did not electrophorese successfully. A probable reason is that the cells lost viability due to pH fluctuations; postmission assessment revealed only 6 percent viability. The isotachopheresis was partly successful; only front boundaries developed. No zone separation or rear boundaries were evident because the processing time was too short. From a research application viewpoint, the most significant result was the kidney cell separation. Zones were formed and yielded concentrations of urokinase-producing cells, as demonstrated by subsequent laboratory culturing. Although the lymphocyte processing was not successful, preservation techniques were developed in preparation for the experiment that may eventually allow blood donors to donate blood years in advance of intended use, as opposed to some present requirements of donating within 2 days of intended use.

The Electrophoresis Experiment developed an anomaly in its photo-optical detection system. During flight, the lamps were 42 percent brighter than their nominal values, which resulted in saturation of the photodiode detector array. Consequently only optical absorptions greater than 30 percent were detectable, and 30 percent was the upper limit expected for light absorption by the separated streams. However, absorption pulses did appear on the data tape with a distribution similar to that expected for the separated streams. Subsequent ground tests revealed that the cells subjected to electrophoresis tend to aggregate irregularly in the regions of the electrophoretically separated streams such that the pulse distributions do provide good representations of the separated cell-stream distributions. On the basis of this indirect evidence for successful electrophoresis, the result was that electrophoresis was accomplished with a tenfold increase in the throughput rate and with at least as sharp cell separation as is achievable in a one-g environment. The rat spleen cells achieved the sharpest separation. The rat lymph node cells achieved excellent

separation and apparently exhibited the greatest tendency to form aggregations (viz, provided the greatest number of pulse data). The rat bone marrow cells indicated good separation in spite of few data (viz, they tended not to aggregate), and insufficient data were available for conclusions concerning the separation of human and rabbit red blood cells.

SOLID MATERIALS PROCESSING

Two types of solid materials processing were conducted on the ASTP mission: high-temperature and low-temperature. The high-temperature processing consisted of melting and solidifying seven sets of materials samples in an electric furnace. They constituted seven separate experiments to investigate mechanical, optical, electrical, and/or magnetic properties of pure and mixed substances that were processed in the absence of sedimentation and thermal convection effects during their liquid phases. Three of the experiments were extensions of furnace investigations begun during Skylab missions, three were entirely new investigations, and one was a jointly conducted experiment. The low-temperature processing was a single experiment that attempted to grow commercially important crystals in water at ambient Apollo cabin temperature. This was the first such experiment performed in a space environment. The development and implementation of this experiment also incorporated cost sharing between NASA and a commercial firm.

The Multipurpose Furnace Experiment was actually a development effort to provide a facility for processing the seven high-temperature experiments during the mission. The ASTP furnace was developed from the Skylab furnace and provided higher processing temperatures (nominally 1423 K) with no increase in power requirement. Also, circuitry was added to allow controlled, variable-rate cooldown; and a helium-injection rapid-cooldown system was developed to reduce the cool-to-touch time from 20 hours to as few as 3 hours. Thus, more experiments could be processed during the mission. Each experiment provided a set of three stainless steel cartridges (fig. 1-16), and each cartridge contained between one

and three ampoules of material to be processed. All three cartridges were processed simultaneously. The furnace system operated extremely well throughout the mission, except during the first use of the helium cooldown system. This anomaly resulted in a longer soak time for the first experiment, but no notable degradation was observed in the scientific results and no further system anomalies occurred during the mission.

The Surface-Tension-Induced Convection Experiment was an attempt to detect the convective mixing in melted material in micro-g that might be due to surface-tension gradients arising from compositional gradients. The material selected was pure lead interfaced to an alloy of lead and 0.05 atomic percent gold, and samples were processed in both wetting and nonwetting ampoules. The processed samples revealed that incomplete mixing occurred in a pattern not explainable by diffusion. The flow pattern occurred where the material contacted the nonwetting ampoule surface, and the best explanation appears to be that the flow was induced by interfacial tension gradients arising most likely from the compositional gradient, a demonstration of the Marangoni

effect. These results are surprising because they suggest that the well-known hydrodynamic no-slip condition may not be valid in micro-g conditions. (However, see discussion of Interface Marking in Crystals Experiment.)

The Monotectic and Syntectic Alloys Experiment was an investigation of the effects of micro-g melting and solidification of two materials, aluminum antimonide (AlSb) and lead-zinc (Pb-Zn). Aluminum antimonide is potentially an efficient solar-cell material, perhaps 30 to 50 percent more efficient than silicon. The problems with this material have been difficulty in obtaining stoichiometric homogeneity in the compound and the fact that this material is highly reactive with moisture. This latter problem may be caused by electromotive force effects due to the presence of Al-rich and Sb-rich secondary phases that occur within the compound in one-g processing. The samples processed during ASTP reveal major improvements in macroscopic and microscopic homogeneity. They contain an average of 4 times, and a maximum of 20 times, less of the undesirable secondary phase. Small amounts of the Al-rich phase are found only along parts of the grain boundaries, whereas samples

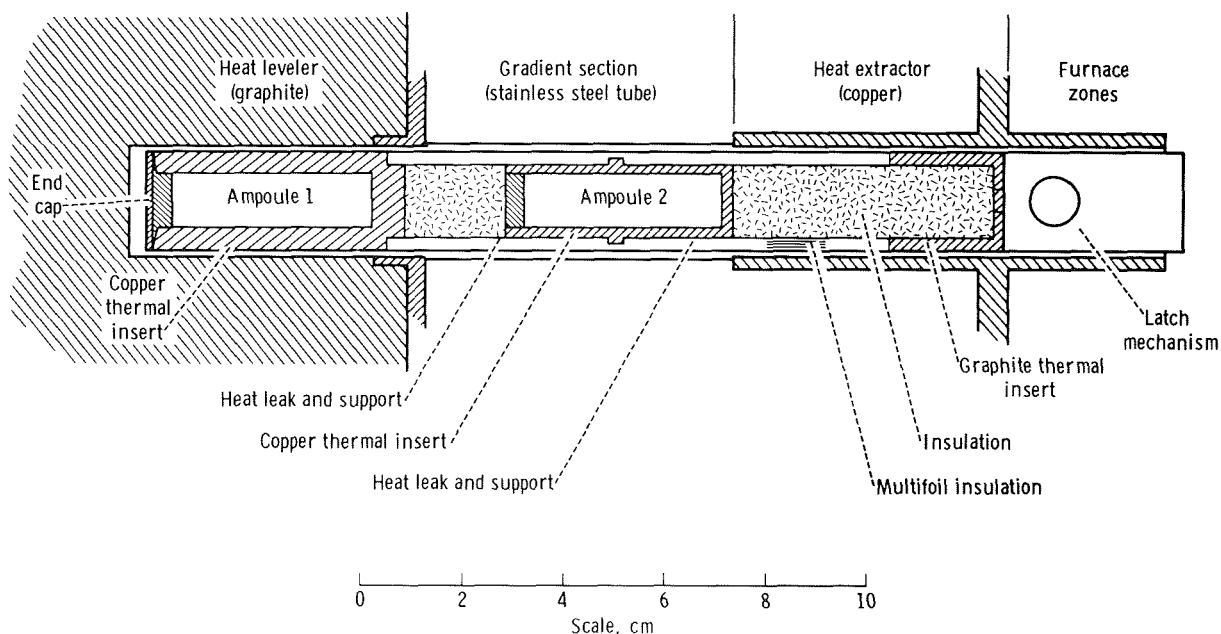


FIGURE 1-16.—Multipurpose furnace typical cartridge assembly.

processed in one-g conditions contain major grains of both the Al-rich and Sb-rich phases. The Pb-Zn system was studied to investigate the phase-segregation effects in micro-g conditions for this immiscible system. Because of the large density differences between lead and zinc, it is difficult in one-g conditions to prevent gravity separation during resolidification. It was hoped that the space-processed samples would result in a dispersion of fine particles of superconducting lead in a zinc-rich composition. However, the space-processed samples failed to mix, even though the soak temperature was 40 K above the published miscibility gap. Although some Pb particles were dispersed in the Zn matrix, the bulk of the lead remained in the same position as before melting.

The Interface Marking in Crystals Experiment was designed to investigate the crystal growth and segregation characteristics in a directionally solidifying material. For this purpose, gallium-doped germanium crystals grown on Earth were partly melted and resolidified as 55-millisecond current pulses (19.1 A cm^{-2}) were transmitted across the traveling solid/melt interface at intervals of 4 seconds. The Peltier cooling by the current pulses at the interface caused time-identifiable demarcations that enabled determination of growth rates. Many new results were revealed. No wetting of the ampoule by the material occurred, as opposed to ground-based processing. The possibility that wetting inversion in space is a phenomenon occurring for many systems has significant implications for materials-processing technology in space applications. The measured growth rate increased rapidly from 0 to $7 \mu\text{m sec}^{-1}$ at the onset of cooling, continued to increase over a distance of 2.5 cm, and then reached a constant value of $10.5 \mu\text{m sec}^{-1}$. The growth-rate behavior was the same for the ground-processed samples, an indication that the heat transfer was dominated by conduction (since laminar convection was present in the ground-based tests). All segregation theories assume a step-function jump from zero to constant-growth rate; therefore, these results require the development of a modified segregation theory. The segregation results show that, as expected, the dopant concentration increased in the bands as the interface

traveled over approximately 1.5 cm. However, with continuing growth (at a rate that was still increasing), the dopant concentration decreased rather than reaching an expected steady-state value. It is most likely that this unexpected behavior is a feature of the geometry of the growth system rather than a characteristic of growth in micro-g conditions.

The Zero-g Processing of Magnets Experiment was designed to investigate the possibility of enhancing the magnetic coercive strength of materials, which may have important technological application in the future. The two magnetic materials tested were alloys of manganese-bismuth (Mn-Bi) and copper-cobalt-cerium (Cu-Co-Ce). The results were significant. Chemical homogeneity was substantially enhanced macroscopically and microscopically. Primary single crystals were grown that exceeded the sizes of Earth-grown crystals by a factor of 10. (Crystal size was limited by the ampoule dimension.) The Mn-Bi samples yielded significantly improved coercive strength, exceeding previously reported values by 20 to 100 percent. In the unannealed state, values exceeding 15 MA m^{-1} were achieved; at this writing, measurements are underway for the annealed state. The Cu-Co-Ce samples did not show enhanced magnetic properties. The problem with the flight samples was similar to problems encountered with Earth-based processing of rare earth materials. The material reacted with the crucible material of the ampoule to form an intermetallic reaction layer, which resulted in spurious nucleation of the magnetic phase ahead of the regrowth interface.

The Crystal Growth From the Vapor Phase Experiment was an extension of a Skylab experiment to generalize and characterize the micro-g crystal growth of a class of compounds from the vapor phase. The Skylab experiment revealed that improved crystalline perfection and much greater than expected mass transport rates occurred for germanium selenide (GeSe) and germanium telluride (GeTe) using germanium tetraiodide as a transport agent. Crystal growth from the vapor phase for such compounds in the IV to VI class of materials is of major interest because the electronic properties are critically dependent on the degree of chemical homogeneity and

crystalline perfection. The ASTP experiment included new compounds and solid solutions transported with different transport agents in higher temperature gradients. The results confirm the Skylab results and extend the conclusions to more complex systems. They also provide experimental evidence for the cause of the enhanced transport rates over the theoretically predicted values. The homogeneity improvement in distribution of tellurium in the germanium-selenium-tellurium starting sample is approximately a factor of 10. The corresponding improvement in distribution of selenium in the germanium-sulfur-selenium starting sample is less pronounced. In micro-g conditions, the transport rates were equal to or lower than rates on the ground, but they were three to five times greater than any diffusion theory would predict for micro-g conditions. Furthermore, the enhanced rates cannot be explained solely on the basis of a diffusion process. The enhanced rates are most probably related to thermochemical effects of gas-phase reactions that have not been included in current vapor transport models.

The Halide Eutectic Growth Experiment was an attempt to grow continuous fibers of lithium fluoride (LiF) in a matrix of sodium chloride (NaCl). The objective was to demonstrate the advantages of micro-g processing for obtaining infrared-transmitting fiber optics. This experiment was an extension of a similar Skylab experiment in which long fibers of sodium fluoride were grown in a matrix of sodium chloride. For the Apollo-Soyuz experiment, ingots of the LiF-NaCl eutectic were partly melted and directionally resolidified in micro-g conditions. Continuous LiF fibers were obtained, which yielded improved transmittance over a wider wavelength range with better image quality compared to ground-processed samples.

The Multiple Materials Melting Experiment had several objectives. This jointly conducted experiment was analyzed exclusively by the U.S.S.R. investigators, and their results are published in this document. Three ampoules containing different materials were placed in each cartridge. One sample consisted of an aluminum rod with seven tungsten balls fused to one end and a rod of tungsten-rhenium alloy fused to the other. The

objectives were to investigate formulation of compounds with components of highly different specific weights and to investigate diffusion and formation of intermetallic phases as a result of interaction of refractory inclusions in a meltable matrix. The inclusions were shifted during space processing, perhaps due to in-flight spacecraft accelerations. The second ampoule contained an antimony-doped germanium-silicon solid solution. The purpose was to obtain monocrystals of homogeneous distribution of this semiconductor material. Monocrystals were obtained with and without seeding by means of directional solidification, but with heterogeneous distribution of components possibly due to radial temperature gradients in the furnace. The third ampoule contained aluminum powder and small pieces of copper-aluminum eutectic to investigate, for example, sphere formation. The space-processed samples showed no significant differences from the ground-processed samples.

The Crystal Growth Experiment was the first attempt in space to demonstrate the possibility of growing commercially important crystals by diffusion of appropriate reactants toward each other through pure water at low temperature (viz, ambient spacecraft cabin temperature). Low-temperature methods avoid some of the complications associated with high-temperature processing, such as phase transitions, component volatility, thermally induced strain, and contamination from the container. The most successful ground-based, low-temperature crystal growth process has been the gel method, in which reactants diffuse toward each other through a gel. The function of the gel is to support the growing crystals and suppress convection. The main problems are reduced diffusion rates through the gel and multiple nucleation of crystals in the gel, which combine to prevent the growth of large single crystals, and possible contamination of the crystals by the gel material. Because the crystals presumably do not need convection suppression or crystal support in micro-g conditions, the gel can be replaced by pure water. The crystals were grown in reactors (fig. 1-17); compartment A contained the water, and the reactants were stored in compartments B and C. After the joint phase of the mission was completed and the Apollo and

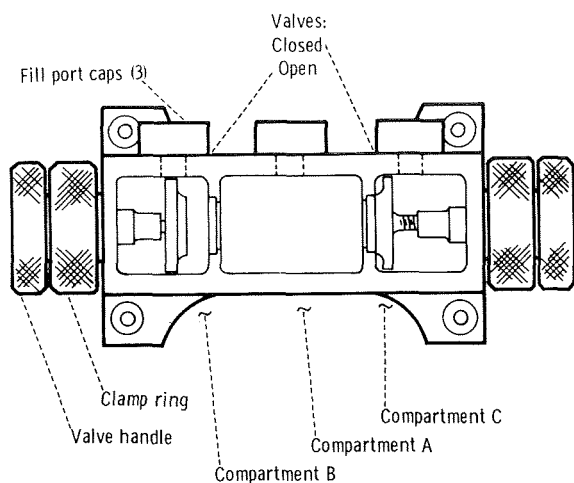


FIGURE 1-17.—Crystal growth reactor.

Soyuz spacecraft had separated, compartments B and C were opened and the reactants diffused toward each other. The crystals grown were calcium tartrate, calcium carbonate, and lead sulfide. The best crystals obtained were the calcium tartrate, with prismatic shapes as long as 2 mm and plate shapes as long as 5 mm. Many rhombohedral calcium carbonate crystals as large as 0.5 mm on a side were formed. The lead sulfide reaction was less successful, but it produced small crystals as large as 0.1 mm. However, the lead sulfide reaction was not complete at time of reentry. The need for temperature control was evident for all the reactions; the temperature in the command module ranged from 289 to 297 K during the flight. The crystals obtained were of a size and quality comparable to the best obtainable in one-g conditions in the same length of time.